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SPECIFICATIONS AN..(U) CAL RECOVERY SYSTEMS INC
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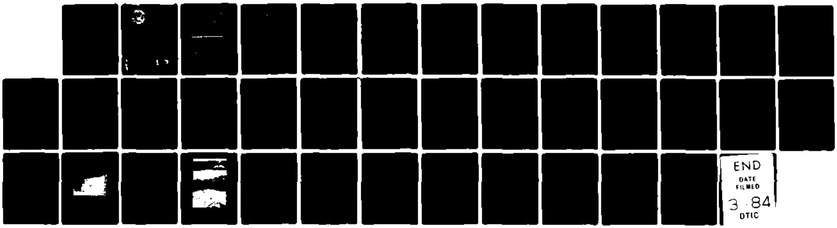

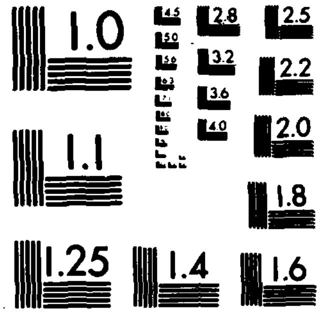

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

TECHNOLOGY EVALUATION FOR DENSIFIED REFUSE-DERIVED FUEL SPECIFICATIONS AND ACQUISITION

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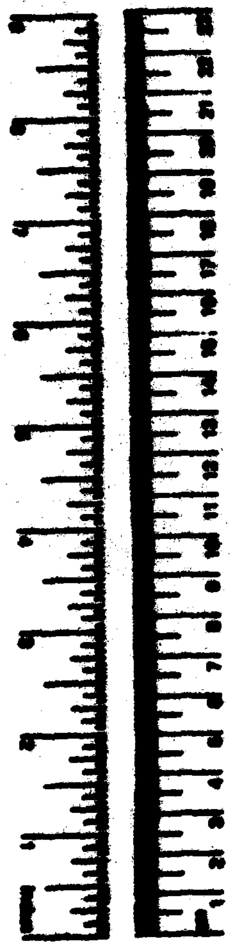
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

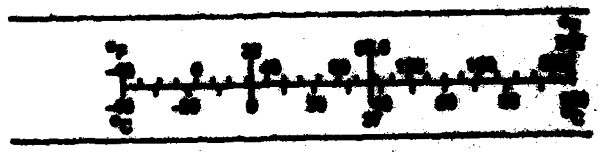
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report determines existing and feasible specifications for densified Refuse Derived Fuel (d-RDF) to be used on military installations. The d-RDF specifications are compared to specifications for coal and wood. Site visits to two RDF facilities were conducted. Recommendations on improvements to existing d-RDF specifications are made.

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TABLE OF CONTENTS

1.0 Introduction

This report has been prepared to assess the existing specifications for dRDF to be used at military installations. The assessment has been based upon the current state-of-the-art of dRDF production and that technologically feasible in the near future. The specifications and reported properties for dRDF have been compared with those of coal and wood. The comparison has been made in order to: 1) establish their similarities and differences, and 2) provide an overview of those fuels that may be used in the stoker-fired, traveling grate boilers operated by the military. Also, as part of this work effort, site visits were conducted to assess the production of dRDF at the Baltimore County, Maryland, resource recovery facility and the dRDF receiving and firing system at Wright-Patterson AFB. These assessments were conducted in light of the existing dRDF specifications in order to document their suitability and comprehensiveness. The findings of this study show that certain deficiencies exist in the present dRDF specifications, and that data are lacking for establishing certain necessary dRDF properties. In addition, the range of dRDF properties that may be met through existing resource recovery technologies are presented.

At the conclusions of the report, recommendations are offered for defining an improved set of dRDF specifications, improving the dRDF product presently being supplied to Wright-Patterson, and establishing a comprehensive list of dRDF properties.

2.0 Solid Fuel Properties and Specifications

2.1 DENSIFIED REFUSE DERIVED FUEL (dRDF) PROPERTIES

The establishment of specifications for dRDF is a compromise between the properties of the product that can be supplied by a producer and the properties that are required by the user in his combustion system. In order to evaluate the product that can be supplied, members of CRS assessed the properties of enhanced (or "high quality") RDF and dRDF that have been reported for a number of different processing systems. Enhanced RDF is that which has been subjected to some form of processing to remove the major portion of the fine, inert materials commonly inherent in unscreened, shredded air classified light fraction. These inert materials are typically dirt and glass fines. For the purposes of this study, it has been assumed that densifying RDF changes only the density of the fuel with only minimal changes in the other fuel characteristics.

An extensive matrix of RDF and dRDF properties is shown in Table 2.1 for nine different facilities. For some facilities, as shown in the table, data are available for different time periods. Table 2.2 presents averages and ranges of properties of enhanced RDF based upon the entries presented in Table 2.1.

Some results of analyses of ash fusion temperatures are available for dRDF and are shown in Table 2.3. The dRDF for which the test data are reported is air classified light fraction that has not been processed for removal of fines. However, since the main component of RDF ash is glass (SiO_2), the fusion temperatures given in the table are deemed representative of those to be expected of enhanced dRDF. For comparative purposes, the fusion temperatures of glass are also shown in the table.

The ash fusion temperatures of RDF are lower than those for coal as will be discussed later in the report.

Existing dRDF Specifications

A comparison of the average properties of enhanced RDF with the specifications for dRDF set forth by the Air Force (Table 2.2) shows that the specification for heating value could probably be raised to at least 7000 Btu/lb on a dry weight basis. The upper limit on the specification for heating value would probably be about 7500 Btu/lb inasmuch as the standard deviation is on the order of 500 Btu/lb. On the other hand, as shown in Table 2.2, the Air Force specifications for both ash content and bulk density are greater than the average values that can be achieved. Although RDF having ash contents of 8 to 15 percent can be produced, these low values require careful processing and quality control. Such levels of process control are not commonly exercised by production facilities except for short time periods. In other words, the average value of ash content for enhanced RDF should be expected to be in the range of 15 to 20 percent unless there is an incentive to exercise tighter process control. Penalties enacted for ash contents above 15 percent, or alternatively rewards for ash contents below 15 percent, should be considered

Table 2.1. Properties of Enhanced RDF

	Papakube[a]		Aenco[b]	Ames		Tele-dyne[d]	Vista Chemical			Univ. of CA Berkeley		Black Clausen	Americology		Pompano Beach[c]
Date of Data	8/78	5/79	1/76	3/79		8/80	1/76[e]	1/76[e]	3/79[f]	1/76[e]	8/78[g]	9/75[m]	1/80[j]	12/80[k]	12/80
Fuel Type	Fluff	dRDF	Fluff	Fluff[c]	Fluff[c']	dRDF	Fluff	dRDF	dRDF	Fluff	dRDF	dRDF	Fluff	Fluff	Fluff
Heating Value, Btu/lb (dry)	7700	7100	7600	7488	7626	8204	7450	7130	6890	7940	NA	7400	6909	7440	8483
Ash Content, percent (dry)	15	15	17	10	10	16	19	19	15	14	11	14	30	28	10
Moisture Content (percent)	6	28	24	18	24[l]	17	25	12	18	24	19	22	7	26	20[l]
Bulk Density (lb/ft^3)	NA	NA	NA	NA	NA	28	NA	25	NA	NA	NA	30	NA	NA	NA
Pellet Density, (lb/ft^3)	NA	NA	NA	NA	NA	NA	NA	35	NA	NA	74[h]	NA	NA	NA	NA
-3/8" Fines (as-received)	NA	NA	NA	NA	NA	12[i]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Matter, percent (dry)	NA	73	72	NA		NA	67	65	60	NA	NA	77	57	64	NA
Ultimate Analysis, percent (dry)															
H	6	6	6						6				5		
C	43	41	35						38				31		
N	0.5	0.4	0.6						3				1		
O	36	37	41						39				23		
S	0.3	0.3	0.2						0.1			0.2	0.3		
Ash Analysis, percent (dry)															
SiO_2											28			47	
Al_2O_3											31			10	
Na_2O											7			4	
CaO											5			15	
Fe_2O_3											5			2	
MgO											0.9			0.1	

Table 2.1 Properties of Enhanced RDF (Continued)

Notes to Table

a) "Conversion of Navy Waste to dRDF by the Papakube Process and Identification of Commercial Sources," Cal Recovery Systems, Inc, July 1979.

b) "Air Classify First, then Shred," Nollet, A.R. and Sherwin, E.T., Proceedings of the 1978 ASME National Waste Processing Conference, May 1978.

c) "Evaluation of the Performance of the Disc Screens Installed at the City of Ames, Iowa, Resource Recovery Facility," Fiscus, D.E., et al, Proceedings of the 1980 ASME National Waste Processing Conference, May 1980.

c') Calculated from data prepared by Cal Recovery Systems under EPA Contract, "Comparative Study of Air Classifiers," to be published 1981, (average of three air flow settings).

d) Laboratory results Hudson Laboratories, 1976.

e) Laboratory results Reitz Laboratories, 1976.

f) "Thermogravimetric Analysis of Solid Refuse-Derived Fuels and Coal," Hathaway, S.A. and Lin, J.S., U.S. Army Construction Engineering Research Laboratory Technical Report E-49, March 1979.

g) Unpublished University of California (Berkeley) data.

h) Average density for three different pellet diameters (1/2", 3/4", and 1").

i) Samples taken after shipping from Baltimore to Dayton.

j) "Corrosion Probe Evaluation of Broiler Tube Materials During Cofiring of Prepared Refuse and Coal," Proceeding of the Seminar on Municpal Solid Waste as a Utility Fuel, Sponsored by the Electric Power Research Institute, January 9-11, 1980.

k) "Effects of Screening and Drying on WEPCO RDF," Cal Recovery Systems, Inc., EPRI research program, report in review, December 1980

l) Air dry moisture content plus 9 percent.

m) "District Heating With Refuse Derived Fuel at Wright-Patterson Air Force Base," Buonicore, A.J. and Waltz, J.P, USAF, Wright-Patterson AFB, Ohio, September 1975.

Table 2.2. Average and Ranges of Properties of Enhanced RDF and dRDF

Property	Number of Data Points	Range	Average	Std. Dev.	Air Force dRDF Specifications
Heating Value, Btu/lb (dry)	14	6890–8431	7525	460	≥ 6500
Ash Content, percent (dry)	15	10–30	16.6	7.3	≤ 15
Moisture Content (percent)	15	6–28	19.3	6.6	≤ 20
Bulk Density (lb/ft^3)	3	25–30	27.7	2.5	≥ 35
Pellet Density (lb/ft^3)	2	35–74	I[a]	I	None
-3/8" Fines (as-received)	1	I	I	I	≤ 5
Volatile Matter, percent (dry)	8	60–77	66.9	6.8	None
Ultimate Analysis, percent (dry)					
H	5	5–6	5.8	0.4	None
C	5	31–43	37.6	4.8	None
N	5	0.4–3.0	1.1	1.1	None
O	5	23–41	35.2	7.1	None
S	6	0.1–0.3	0.2	0.1	None
Ash Analysis, percent (dry)					
SiO_2	2	28–47			None
Al_2O_3	2	10–31			None
NA_2O	2	4–7			None
CaO	2	5–15			None
Fe_2O_3	2	2–5			None
MgO	2	4–7			None
	2	0.1–0.9			None

a) = Data only available from one source and was measured after shipment to the burn site.

Table 2.3. Ash Fusion Temperatures for dRDF and Glass

	NCRR dRDF[a]		Glass[b]
	Reducing Atmosphere	Oxidizing Atmosphere	Oxidizing Atmosphere
Initial Deformation	1875	1920	1580
Softening	1945	1998	-
Hemisnperical	2007	2068	1740
Fluidity	2160	2150	2000

a) Alter, H. and Campbell, J.A., "The Preparation and Properties of Densified Refuse-Derived Fuel," American Chemical Society, Thermal Conversion of Solid Wastes and Biomass, 1980. The dRDF tested was air classified light fraction and is therefore, not an enhanced RDF. However, the ash fusion temperatures are deemed representative of those to be expected from enhanced dRDF due to the fact that the ash of RDF fractions (enhanced and air classified light fractions) are typically 50 percent SiO_2.

b) Average of values reported for clear, brown, and green glass, "Prevention of Fused Deposits on Incinerator Lower Side Walls," Proceedings of 1968 ASME National Incinerator Conference.

to induce suppliers to meet the 15 percent limit for ash content. A reduction of the ash content of the fuel would minimize problems associated with handling, storage, and disposal of the ash. In addition, environmental as well as financial impacts associated with ultimate disposal of the ash would be reduced.

The specification of a minimum bulk density of 35 lb/ft^3 is considerably greater than the range of 25 to 30 lb/ft^3 that has been reported, as shown in Table 2.2. Based upon the limited amount of data (three reported values), it appears that the Air Force's bulk density specification may be too stringent. The need for this specification may be mute since it may be supplanted by one specifying the moisture content, density, diameter, and length of the pellets. A specification cast in this manner would serve not only to assure pellets of high integrity (i.e. hard, dense pellets) but would also assure pellets with a minimum content of fines as a consequence of their high integrity.

The Air Force specification for moisture content ($\geq$ 20 percent) falls quite close to the average value shown by the data (19.3 percent) in Table 2.2. However, there is a significant standard deviation (7.3 percent) probably due to the fact that there is a wide variability of refuse moisture content due to seasonal trends (e.g. moisture-ladened lawn and garden debris during the spring and summer months). Since this moisture will be picked up by some of the other combustible components of RDF (e.g. paper), in the opinion of CRS it is seldom technically possible, on the part of the producer, to provide pellets over a yearly period with moisture contents of less than 20 percent. In addition, moisture changes in the dRDF can also take place during storage and transportation. A range of 17 to 24 percent should be expected unless a drying step is imposed during or after processing.

2.2 COAL

Properties of Various Coals

Coals may be classified in various ways: by rank, by variety, by size, and sometimes by use. Classification by rank is typically based upon the degree of change in the series between lignite and anthracite. The classification of coals by rank adopted by the American Society for Testing and Materials (ASTM) is presented in Table 2.4. This classification is based upon the fixed carbon and heating value of the coal. Both of these parameters are calculated on a mineral-matter-free basis.

Coals can also be classified into two general types according to the composition of their ash. Coals having a higher concentration of Fe_2O_3 in their ash than the combined concentrations of CaO and MgO are known as "bituminous." In the cases where the combined concentrations of CaO and MgO in the ash are higher than that of Fe_2O_3, the coals are classified as "lignite."

The analyses of various ranks of coal on an as-received basis are presented in Table 2.5. The data in the table show that the heating value of coal can vary from about 6,000 to 14,000 Btu/lb. The ash content can fluctuate from 4 to 19 percent while the moisture content can be as low as 3 percent and as high as 36 percent.

Table 2.4. Classification of Coals by Rank[1]

(FC = Fixed carbon; VM = Volatile matter; Btu = British thermal Units)

Class	Group	Limits of Fixed Carbon or Btu Mineral-Matter-Free Basis	Requisite Physical Properties
	1. Meta-anthracite	Dry FC, 98 or more	
		Dry VM, 2 or less	
I Anthracitic	2. Anthracite	Dry FC, 92-98	
		Dry VM, 2-8	
	3. Semianthracite	Dry FC, 86-92	Nonagglomerating[2]
		Dry VM, 8-14	
	1. Low-volatile bituminous	Dry FC, 78-86	
		Dry VM, 14-22	
	2. Medium-volatile bituminous	Dry FC, 69-78	
		Dry VM, 22-31	
II Bituminous[3]	3. High-volatile A bituminous	Dry FC, less than 69	
		Dry FM, more than 31	
		Moist[4] Btu, 14,000 or more	
	4. High-volatile B bituminous	Moist[4] Btu, 13,000-14,000[5]	
	5. High Volatile C bituminous	Moist Btu, 11,000-13,000[5]	Either agglomerating or nonweathering[6]

Table 2.4. Classification of Coals by Rank[1] (Continued)

(FC = Fixed carbon; VM = Volatile matter; Btu = British thermal Units)

Class	Group	Limits of Fixed Carbon or Btu Mineral-Matter-Free Basis	Requisite Physical Properties
III Subbituminous	1. Subbituminous A	Moist Btu, 11,000-13,000[5]	Both weathering and nonagglomerating
	2. Subbituminous B	Moist Btu, 9,500-11,000[5]	
	3. Subbituminous C	Moist Btu, 8,300-9,500[5]	
IV Lignitic	1. Lignite	Moist Btu, less then 8,300	Consolidated
	2. Brown coal	Moist Btu, less than 8,300	Unconsolidated

[1]ASTM D 388 does not include a few coals of unusual physical and chemical properties which come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks.
[2]If agglomerating, classify in low-volatile group of the bituminous class.
[3]There may be noncaking varieties in each group of the bituminous class.
[4]Moist Btu refers to coal containing only its natural bed moisture.
[5]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis are classified according to fixed carbon regardless of Btu.
[6]There are three varieties in the high-volatile C bituminous coal group, 1) agglomerating and nonweathering, 2) agglomerating and weather, and 3) nonagglomerating and nonweathering.

Table 2.5. Analysis of Some Coals as Received[a]

Location	Arkansas (Johnson Co.)	Kentucky (Muhlenburg Co.)	Wyoming (Sweetwater Co.)	North Dakota (McLean Co.)	Typical Range
Rank	Semianthracite	High-Volatile B	Subbituminous A	Lignite	
Heating Value (But/lb)	13,880	11,680	10,650	7,000	6,000–14,000
Ash Content (percent)	7.5	10.8	3.6	5.9	4–19
Moisture Content (percent)	2.6	8.5	16.9	36.8	3–36
Bulk Density (lb/ft^3)	NR[b]	NR	NR	NR	40–60
Volatile Matter (percent)	10.6	36.4	34.8	27.8	3–37
Fixed Carbon (percent)	79.3	44.3	44.7	29.5	30–80
Ultimate Analyses (percent)					
H	3.8	5.4	6.0	6.9	2–7
C	81.4	65.1	60.4	40.6	40–80
N	1.6	1.3	1.2	0.6	0.6–1.6
O	4.0	14.6	27.4	45.1	4–45
S	1.7	2.8	1.4	0.9	0.3–4.0

a) Marks Standard Handbook for Engineers, Baumeister, et al, Eighth Ed., 1978.
b) NR = not reported

The bulk density of coal is affected by the size distribution, specific gravity, and moisture content of the coal. However, in general, coal can have a bulk density ranging from 40 to 60 lb/ft^3.

The volatile matter content of coal can range from 3 percent in "low-volatile" coals to 36 percent in "high-volatile" bituminous coals.

Fixed carbon, the material that remains after the volatile matter is driven off, usually fluctuates between 30 and 80 percent.

Coal consists primarily of carbon (40 to 80 percent) and oxygen (4 to 45 percent). Other constituents include hydrogen, nitrogen, and sulfur, having concentrations within 0.3 to 7 percent.

Knowledge of the composition of coal ash is extremely useful in determining the clinkering and slagging characteristics of the fuel within the fuel bed and on heat transfer surfaces. The results of ash analyses of various coals, as well as a typical range of values, are presented in Table 2.6.

The major constituents of coal ash are typically silica (20 to 60 percent), alumina (10 to 35 percent) and ferric oxides (5 to 35 percent). Calcium oxide is also found in concentrations ranging from 1 to 20 percent. Concentrations of magnesium and sodium oxides generally fluctuate between 0.3 and 4 percent.

Properties of Coal Used in the Military

Properties have been compiled from coal analyses provided by the U.S. Navy and the Air Force, and are given in Tables 2.7 and 2.8, respectively. The properties of coals used by the Navy and Air Force are similar. The heating values are in the neighborhood of 14,000 Btu/lb.

Specifications of Coal Used in the Military

Specifications for coal set by the military are presented in Table 2.9 based upon information supplied to CRS by the U.S. Air Force and the U.S. Navy. Data are presented for lump coal only, since this form of coal is most analogous to RDF pellets. A summary of the ranges of specifications for lump coal that exist for the Air Force and Navy, Table 2.10, shows the similarity among the specifications.

2.3 WOOD

Properties

The characteristics of various types of waste wood are presented in Table 2.11. The data in the table indicate that the heating value of dry wood varies between 8200 and 9100 Btu/lb dry, while the ash and moisture contents fluctuate from 0.4 to 2.2 percent and from 36 to 58 percent, respectively.

The volatile matter of dry wood ranges from 70 to 82 percent and the fixed carbon fluctuates from 17 to 27 percent.

Table 2.6. Ash Analysis of Some Coals
(percent dry wt.)[a]

Location	West Virginia	Utah	Wyoming	Texas	Typical Range
Rank	Low Volatile Bituminous	High Volatile Bituminous	Subbitu- minous	Lignite	NA
SiO_2	60.0	48.0	24.0	41.8	20–60
Al_2O_3	30.0	11.5	20.0	13.6	10–35
Na_2O	0.5	1.2	0.2	0.6	1–4
CaO	0.6	25.0	26.0	17.6	1–20
Fe_2O_3	4.0	7.0	11.0	6.6	5–35
MgO	0.6	4.0	4.0	2.5	0.3–4

a) Steam/Its Generation and Use, Babcock and Wilcox, New York, 1972.

Table 2.7. Properties of Coals Utilized in Navy Energy Facilities

Property	Camp Lejeune N.C.	Charles-ton N.S. S.C.	Norfolk P.W. Va	Quantics MCB[b] Va	Average Properties of Navy Coal	Range of Average Properties
Particle Size (inches)	-1 1/4 + 1/4	-1 1/2 + 0	NR[a]	c	-1 1/4 + 1/4	-1 1/2 + 0
Moisture Content (oven dry basis)	2.2	4.0	2.7	5.3	3.6	2.2-5.3
Volatile Matter, percent (oven dry basis)	35.1	36.3	33.3	34.4	34.8	33.3-36.3
Fixed Carbon (percent)	54.7	56.0	61.5	56.8	57.3	54.7-61.5
Ash Content, percent (oven dry basis)	10.2	7.7	5.2	8.8	8.0	5.2-10.2
Heating Value, Btu/lb (oven dry basis)	13,580	13,780	14,490	13,760	13,900	13,580-14,490
Sulfur, percent (oven dry basis)	0.7	1.2	1.0	0.9	1.0	0.7-1.2
Ash Softening Temperature (°F)	NR	NR	NR	2860	I[d]	I
Free Swelling Index	NR	NR	NR	1	I	I

a) NR = Not Reported
b) Averages for nine analyses March 1979 through March 1980.
c) Range of size -1 1/4 + 0, -1 1/2 + 0, -1 1/4 + 1/4 inches
d) I = Insufficient Data

Table 2.8. Properties of Lump Coal Used at Wright Patterson

(Minehead Analysis, -1 1/4" + 1/4" Coal)

	K[a]	B[b]	B	B	K	K	K	B	Avg[c]/S[d]	Speci-fications
Report Date	10/10	10/16	10/15	10/8	10/10	10/10	10/16	10/19		
MC[e], percent (as-received)	2.96	5.52	4.90	5.51	2.56	2.96	2.79	4.53	3.97/1.27	≤ 5.55
Volatile Matter, percent (dry)	38.50	37.92	37.85	37.09	39.67	38.50	40.53	37.70	38.47/1.13	≤ 39.0
Fixed Carbon, percent (dry)	55.36	55.56	56.16	55.95	54.87	55.36	56.77	56.11	55.77/1.31	-
Ash, percent (dry)	6.13	6.52	5.99	6.96	5.46	6.13	2.70	6.19	5.76/1.31	≤ 7.5
Sulfur, percent (dry)	0.69	0.70	0.70	0.70	0.70	0.69	0.71	0.70	0.70/0.01	≤ 0.7
Heating Value, Btu/lb (dry)	14,196	14,000	14,062	13,922	14,121	14,196	14,504	14,035	14,137/197	≥14,000
Free Swelling Index	5	4	4	4	5	5	4.5	4	4.4/0.5	≥ 3
Fusion Temperature (°F)[f]										
Initial	2710	2660	2660	2700	2690	2710	2520	2650	2663/62	-
Softening	2770	2730	2720	2760	2780	2770	2620	2720	2734/52	≥ 2600
Hemisphere	>2800				>2800	>2800	2630			-
Fluid	>2800	2800	2790	>2800	>2800	>2800	2780	2760		-

a) K = Kenwill, Inc. laboratory analyses
b) B = Blue Diamond laboratory analyses
c) Avg = average value
d) S = standard deviation
e) MC = moisture content
f) Reducing atmosphere

Table 2.9. Navy Lump Coal Specifications

	Facility: Charleston	Facility: Cherry Point	Facility: Bangor	Specification Range
Particle Size (inches)	-1 1/2	-1 1/4+1/4	-1 1/4+1/4	≤ 1 1/2
Heating Value, Btu/lb (oven dry basis)	≥ 12,600	≥ 13,500	≥ 13,500	≥ 12,600-13,500
Ash Content, percent (oven dry basis)	≤ 10 ≥ 6	≤ 8	≤ 10	≤ 8-10
Moisture Content (oven dry basis)	≤ 5	≤ 8	≤ 10	≤ 5-10
Volatile Matter, percent (oven dry basis)	≤ 41 ≥ 28	≥ 30	≤ 46	≤ 41-46 ≥ 28-30
Sulfur, percent (oven dry basis)	≤ 1.5	≤ 1	≤ 1	≤ 1-1.5
Ash Softening Temperature (°F)	≥ 2300	≥ 2500	≥ 2200	≥ 2200-2500
Free Swelling Index	≤ 7	NS[a]	NS	

a) NS = No Specifications

Table 2.10. Summary of the Ranges of Specifications for Navy and Air Force Lump Coal

	Navy[a]	Air Force[b]
Particle Size (inches)	≤ 1 1/2	-1 1/2 + 1/4
Heating Value, Btu/lb (oven dry basis)	≥ 12,600-13,000	≥ 14,000
Ash Content, percent (oven dry basis)	≤ 8-10	≤ 7.5
Moisture Content (oven dry basis)	≤ 5-10	≤ 5.5
Volatile Matter, percent (oven dry basis)	≤ 41-46 ≥ 28-30	≤ 39.0
Sulfur, Percent (oven dry basis)	≤ 1-1.5	≤ 0.7
Ash Softening Temp. °F	≥ 2200-2500	≥ 2600

a) Charleston, Cherry Point, Bangor facilities
b) Wright-Patterson facility

Table 2.11. Analyses of Waste Wood Burned as Fuel[a)]

	Jack Pine[b)]	Birch[b)]	Maple[b)]	Eastern Hemlock[b)]	Southern Pine Bark[c)]	Oak Bark[c)]	Oregon Waste Wood[c]	White Fir Bark[c),d)]	Spruce Bark[c),d)]	Redwood Bark[c),d)]	Western Hemlock[f)]	Douglas Fir[f)]	Pine Sawdust[f)]
Moisture Content, percent (dry)	50	50	50	50	UR[g)]	UR	UR	UR	UR	UR	57.9	35.9	UR
Proximate Analysis (percent)													
Ash	2.1	2.0	4.3	2.5	2.9	5.3	2.0	1.7	3.8	0.4	2.2	0.8	0.5
Volatile	74.3	78.5	76.1	72.0	72.9	76.0	74.7	74.3	69.6	72.6	74.2	82.0	78.4
Fixed Carbon	23.6	19.2	19.6	25.5	24.2	18.7	23.3	24.0	26.6	27.0	23.6	17.2	20.1
Ultimate Analysis (percent)													
Carbon	53.4	57.4	50.4	53.6	53.4	49.7	53.9	52.2	51.8	51.9	50.4	52.3	51.8
Hydrogen	5.9	6.7	5.9	5.8	5.6	5.4	5.7	5.8	5.7	5.1	5.8	6.3	6.3
Sulfur	0.0	0.0	0.0	0.0	0.1	0.1	t[e)]	t	0.1	t	0.1	0.0	0.0
Nitrogen	0.1	0.3	0.5	0.2	38.0	39.5	38.4	40.3	38.6	42.6	0.1	0.1	0.1
Oxygen	38.6	33.8	39.1	37.9	38.0	39.5	38.4	40.3	38.6	42.6	41.4	40.5	41.3
Heating Value, Btu/lb	8930	8870	8190	8885	UR	UR	UR	UR	UR	UR	8620	9050	9140
Ash Analysis													
SiO_2	16.0	3.0	9.9	10.0	UR	UR	UR	1.7	32.0	14.3	UR	UR	UR
Al_2O_3	6.3	0.0	3.8	2.1				3.2	11.0	4.0			
Fe_2O_3	5.0	2.9	1.7	1.3				3.2	6.4	3.5			
CaO	51.6	58.2	55.5	53.6				60.8	25.3	6.0			
$CaCO_3$	4.9	13.0	1.4	9.7				3.0	4.1	6.6			
MgO	5.5	4.2	19.4	13.1									
MnO	1.6	4.6	1.0	1.2									
P_2O_5	2.8	2.9	1.1	2.1									
K_2O	4.1	6.6	5.8	4.6									
Mn_2O	3.1	1.3	2.2	1.1									
TiO_2	0.2	t	t	t									
SO_3	2.6	3.2	1.4	1.4									

See footnotes on next page.

Table 2.11. Analyses of Waste Wood Burned as Fuel (Continued)

	Jack Pine[b)]	Birch[b)]	Maple[b)]	Eastern Hemlock[b)]	Southern Pine Bark[c)]	Oak Bark[c)]	Oregon Waste Wood[c]	White Fir Bark[c),d)]	Spruce Bark[c),d)]	Redwood Bark[c),d)]	Western Hemlock[f)]	Douglas Fir[f)]	Pine Sawdust[f)]
Ash Fusion Temperature[g] (°F)													
Initial	2450	2710	2650	2760	2180	2680	UR[h]	UR	UR	UR	UR	UR	UR
Softening	2750	2720	2820	2770	2220	2730							
Fluid	2760	2730	2830	2780	2470	2750							
Bulk Denisty, lb/ft^3 (as-received)	29	37-44	3142	26-29	UR	UR	UR	UR	UR	UR	19.4	17.4	UR

a) Data are for softwoods, hardwoods, and bark.
b) Adapted from information compiled by the Steam Power Committee of the Canadian Pulp and Paper Association and reported in Combustion Engineering, G.R. Fryling, Ed., 1966, Pg. 27-3.
c) Hall, E.H., et al, "Comparison of Fossil and Wood Fuels," EPA Report No. EPA-600/2-76-056, March 1976.
d) Salt-water stored
e) t = trace
f) Combustion Engineering, G.R. Fryling, Ed., 1966, pg. 14-22.
g) Reducing atmosphere is assumed, reference is unclear.
h) UR = unreported

For comparative purposes, some properties of various virgin woods (unprocessed) are shown in Table 2.12. It is noteworthy that the range of heating values and ash contents of virgin wood (8,700 to 9,030 Btu/lb and 0.5 to 0.8 percent) are narrower than those for waste wood (8,200 to 9,100 Btu/lb and 0.4 to 2.2 percent).

The major components of wood are carbon (50 to 57 percent), oxygen (34 to 43 percent), and hydrogen (5 to 7 percent). The concentration of nitrogen varies from 0.1 to 0.5 percent and the sulfur content is generally less than 0.1 percent.

Specifications

There is not a rigid set of specifications for wood utilized as fuel. Typically, virgin wood is not utilized as fuel. Waste wood and bark (timber that has undergone some form of processing and discarded) is used for this purpose. In general, any wood waste with a moisture content of 50 percent or less is a suitable candidate for use as a fuel. By examining the data presented in Table 2.11, an idea can be had of the properties of waste wood utilized as fuel and consequently, what is acceptable from the standpoint of combustion and energy production.

Comparison of Solid Fuel Properties

Based upon the information that has been collected for RDF, coal, virgin wood, and waste wood, a range of properties can be defined for each of the aforementioned solid fuels, Table 2.13. From the table, it can be seen that the properties of these fuels are, in many cases, quite similar. From the standpoint of combustion, the notable exceptions are the realtively high heating value of some types of coal (i.e. generally above 10,000 Btu/lb for bituminous and anthracite coals), the relatively high ash content of dRDF, and the relatively low ash fusion temperatures of dRDF. Both the low ash fusion temperatures and high ash content of dRDF set it apart from coal and wood waste fuels in that they can potentially contribute to problems associated with ash handling, slagging, and clinkering.

It should also be noted that dRDF and wood fuels are typically low in sulfur (i.e. less than 0.3 percent) while the typical range for coal is 0.3 to 4.0 percent. Also shown in Table 2.13 is the fact that the major constituent of the ash of dRDF, coal and waste wood is SiO_2.

Also, included for comparative purposes are the properties of dRDF and military coals, Table 2.14. The same observations pointed out above also apply to the data in Table 2.13.

Table 2.12. Typical Analyses of Various Woods, Dry Weight[1]

	C	H	S	O	N	Ash	Heating Value Btu/lb
SOFTWOODS							
Cedar, white	48.80	6.37	-	44.46	-	0.37	8,400
Cypress	54.98	6.54	-	38.08	-	0.40	9,870
Fir, Douglas	52.3	6.3	-	40.5	0.1	0.8	9,050
Hemlock, Western	50.4	5.8	0.1	41.4	0.1	2.2	8,620
Pine, pitch	59.00	7.19	-	32.68	-	1.13	11,340
white	52.55	6.08	-	41.25	-	0.12	8,900
yellow	52.60	7.02	-	40.07	-	1.31	9,610
Redwood	53.5	5.9	-	40.3	0.1	0.2	8,840
Averages	53.0	6.4	-	39.8	-	0.8	9,330
HARDWOODS							
Ash, white	49.73	6.93	-	43.04	-	0.30	8,920
Beech	51.64	6.26	-	41.45	-	0.65	8,750
Birch, white	49.77	6.49	-	43.45	-	0.29	8,660
Elm	50.35	6.57	-	42.34	-	0.74	8,790
Hickory	49.67	6.49	-	43.11	-	0.73	8,660
Maple	50.64	6.02	-	41.74	0.25	1.35	8,580
Oak, black	48.78	6.09	-	44.98	-	0.15	8,190
red	49.49	6.62	-	43.74	-	0.15	8,710
white	50.44	6.59	-	42.73	-	0.24	8,790
Poplar	51.64	6.26	-	41.45	-	0.65	8,920
Averages	50.3	6.4	-	42.8	-	0.5	8,700

[1] Combustion Engineering, G.R. Fryling, Ed., 1966.

Table 2.13. Range of Properties for Enhanced dRDF, Coal, Virgin Wood, and Waste Wood

Property	Enhanced dRDF	Coal	Virgin Wood	Waste Wood
Heating Value, Btu/lb (dry)	6,890-8,431	6,000-14,000	8,190-11,340	8,190-9,140
Ash Content, percent (dry)	10-30	4-19	0.1-2.2	2-5
Moisture Content (percent)	6-28	3-36	23-60[a)]	36-58
Bulk Density (lb/ft^3) 17-19[a)]	25-30	40-60	20-45[a)]	
Pellet Density (lb/ft^3)	35-74	NA[b)]	NA	NA
-3/8" Fines (as-received)	I[c)]	NA	NA	NA
Volatile Matter, percent (dry)	60-77	3-37	I	70-82
Ultimate Analysis, percent (dry weight)				
H	5-6	2-7	6-7	5-7
C	31-43	40-80	49-59	50-57
N	0.4-3.0	0.6-1.6	0.1-0.3	0.0-0.5
O	23-41	4-45	33-45	34-43
S	0.1-0.3	0.3-4.0	0.0-0.1	0.0-0.1
Ash Analysis, percent (dry)				
SiO_2	28-47	20-60	I	2-32
Al_2O_3	10-31	10-35		0-11
Na_2O	4-7	1-4		-
CaO	5-15	1-20		6-61
Fe_2O_3	2-5	5-35		1-6
MgO	0.1-0.9	0.3-4		4-19
Ash Fusion Temperatures, (°F) Reducing Atmosphere				
Init. Deformation	1,875[d)]	2,520-2,710	I	2,180-2,760
Softening	1,945	2,620-2,780		2,220-2,820
Hemispherical	2,007	>2,800		-
Fluidity	2,160	>2,800		2,470-2,830

a) Combustion Engineering, G.R. Fryling, Ed., 1966.
b) NA = Not Applicable
c) I = Insufficient Data
d) Results from one site only (dRDF air classified light fraction).

Table 2.14. Range of Properties for Enhanced dRDF and Military Coals

Property	Enhanced dRDF[a)]	Lump Coal: Navy Facilities	Lump Coal: Air Force Wright-Patterson AFB
Particle Size (inches)	dia. = 1/2 to 1 length = 1/2 to 3	-1 1/2 + 0	-1 1/4 + 1/4
Heating Value, Btu/lb (oven dry basis)	6890-8430	13,580-14,490	13,922-14,564
Ash Content, percent (oven dry basis)	10-30	5.2-10.2	2.7-7.0
Moisture Content (oven dry basis)	6-28	2.2-5.3	2.6-5.5
Fixed Carbon (percent)	NR[b)]	54.7-61.5	54.9-56.8
Volatile Matter, percent (oven dry basis)	60-77	33.3-36.3	37.1-40.5
Sulfur, percent (oven dry basis)	0.1-0.3	0.7-1.2	0.69-0.71
Ash Softening Temperature (°F)	1945	I[c)]	2620-2780
Free Swelling Index	NR	I	4-5

a) Averages for nine dRDF processes.
b) NR = Not Reported
c) I = Insufficient Data

3.0 Site Vists and Assessments

3.1 WRIGHT-PATTERSON dRDF USE

Burn tests were conducted in Boilers No. 1 and 2 (Building 770) using mixtures of dRDF and coal during the period of May 1979 through May 1980. These boilers are equipped with stoker-fired, traveling grate systems and rated at 80,000 pounds per hour of steam (approximately 80 mm Btu/hr of output). Discussion with Mr. Clyde Farris, the steam plant foreman, and Mr. Thomas Shoup, Chief of Environmental Planning, pointed out that the fines content of the dRDF caused various problems during the one-year dRDF firing program at Building 770. These problems are described below:

1) Dust generation during unloading and conveyance of the dRDF was enough to cause nuisance problems such as employee complaints, unsightly litter, and necessitated cleanup work.

2) Carry over of ignited fine organic particles with the combustion gases into the cyclone collectors caused smoldering and fires.

3) Inadequate distribution of the dRDF occurred over the grates due to the high drag and short trajectory of the fines. This situation caused a non-uniform bed depth resulting in uneven burning and localized "hot spots".

In addition to the problems associated directly with the fines in the dRDF, both slag and clinker formation were experienced with coal/dRDF mixtures. In the case of slag formation mixture of dRDF and coal fared no better or worse than coal-only firing, in the opinion of Mr. Farris. On the other hand, clinker formation was more extensive for coal/dRDF mixtures than for coal-only firing, again in Mr. Farris' opinion. However, neither the slagging nor the clinkering resulting from coal/dRDF firing was considered by Mr. Farris to be a significant problem.

In summary, the fines in the dRDF during the Building 770 test firings were the major impediment to the burning program.

Presently dRDF is scheduled for co-firing with coal in Boiler No. 3 at Building 1240. This unit is a high temperature water unit rated at 100 mm Btu/hr. To date, the problems experienced with dRDF/coal firing from a combustion standpoint have been similar to those experienced at Building 770, namely, carry over of organic particles into the collectors and poor distribution of dRDF over the grates due to unacceptably high concentrations of fines in the dRDF.

In addition to the problems occurring at the boiler, other problems associated with the dRDF handling system located outside of Building 1240, a portion of which is shown in Figure 3.1, have been identified and are listed below.

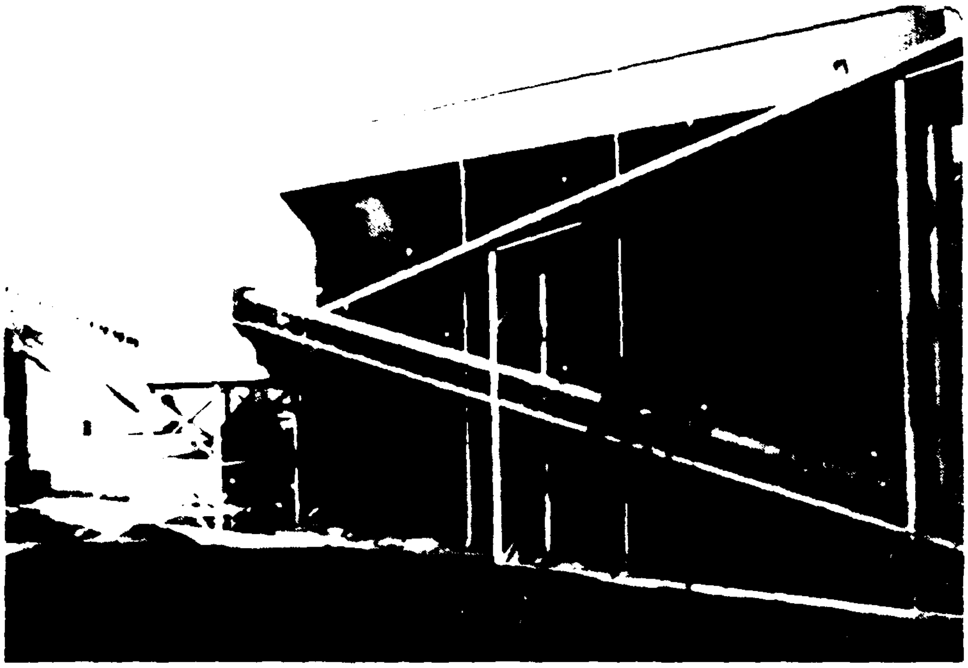

Figure 3.1 Part of the dRDF and coal handling and storage system located at Building 1240

1) According to Mr. Shoup and unloading personnel, some oversize material (i.e. particles greater than 5 inches) has accompanied the dRDF shipments and proceeds to clog the unloading grizzley bars (5 inch x 5 inch rectangular grids) during the unloading of pellet shipments. In addition, oversize material has also been observed to clog the grizzlies (3 inch x 5 inch rectangular grids) located over the storage silos. According to the pellet contractor (Teledyne National), the oversize material is a consequence of not completely emptying the solid waste from the packer trucks used for transporting the pellets from the production facility to the storage warehouse.

2) The fines in the dRDF (loose paper and plastic less than approximately 0.5 inches which apparently break apart from the pellets during handling) disperse during unloading creating uncomfortable working conditions for the unloading personnel and litter about the unloading facility. An example of the accumulation of fines is shown in Figure 3.2.

3) The fines also litter the material handling equipment and transfer points. Dust from the dRDF was noticed to be 0.5 to several inches thick on and around the conveyors. The fines on and around the conveyors tends to be finer (perhaps 14 mesh (0.05 inches) or less in particle size) than that observed around the unloading area. The origin of this fine material has not been identified although fine particles resulting from the pelletizing process and not sufficiently compressed into pellet form may work themselves loose during handling and thus contribute to the dust problem.

4) Wet pellets (perhaps greater than 20 percent moisture) cause plugging problems in the hoppers. Wet pellets lack sufficient integrity to resist the magnitude of forces exerted at the bottom of a twenty to thirty foot depth of pellets. At such pressures, the pellets deform and form a cohesive mass which only increases in density (compaction) in response to efforts to move the mass by force. Typical methods used to remove a clogged (or stuck) hopper include entering at the top of the hopper and using shovels, poles, and clamshells to dig out the material.

3.2 TELEDYNE NATIONAL dRDF PRODUCTION

Teledyne National presently is under contract with the Air Force to supply dRDF for the Wright-Patterson burn tests. Based upon analyses conducted by Howard Laboratories, the Teledyne dRDF exhibited the properties shown in Table 3.1 during the period of 31 March through 27 August 1980. It should be noted that the analyses were conducted after delivery of the dRDF to Wright-Patterson Air Force Base.

The average laboratory values for the dRDF analyses indicate that the pellets are meeting specifications for heating value and moisture content. On the other hand, average ash content, bulk density, and fines

This photo shows the accumulation of fines along the curb bounding the unloading area.

Closeup of area around pencil shown in the top photo. Pieces of paper and plastic that have worked loose from the pellets are visible at the left center of the photo. In addition, fines are evident among the pellets. Fine material similar to that shown above also accumulated on and about the dRDF material handling equipment.

Figure 3.2

Table 3.1. Teledyne dRDF Properties

3/31/80 Through 8/27/80

Property	Average	Standard Deviation	RFP Specification[a]	Teledyne Guaranteed[b]
Heating Value, Btu/lb (oven dry basis)	8204[c]	1081	$\geq$6500	$\geq$7000
Ash Content, percent (oven dry basis)	16.3[d]	4.7	$\leq$15	$\leq$15
Moisture Content[e], percent (oven dry basis)	17.2[c]	6.6	$\leq$20	$\leq$20
Bulk Density[e], lb/ft^3 (as-received)	28.0[d]	0.9	$\geq$35	$\geq$35
-3/8" Fines[e], percent (as-received)	11.9[d]	6.8	$\leq$5	$\leq$5

[a] Solicitation F3360179R008, Page 64

[b] Teledyne Proposal, Page 33

[c] Property value is within RFP and Teledyne guaranteed specification

[d] Property value is not within RFP and Teledyne guaranteed specification

[e] Specified as F03 WPAFB

content exceed specification. Of the three properties not conforming to specification, the latter (fines content) exceeds the specification by more than 200 percent and is directly contributing to dust generation during unloading and conveying and causing the nonuniform distribution of dRDF over the grates.

During visits to observe pellet production at Teledyne, the visual quality of the pellets (as measured by the degree of densification and pellet geometry) has been observed to be good. There is, however, no testing or analyses conducted on the pellets immediately after production in order to quantify what can be visually observed nor the variations (seasonal or daily) that can be expected.

4.0 Recommendations

Based upon site visits to the Baltimore County facility and Wright-Patterson, an assessment of the state-of-the-art of RDF and dRDF processing, and the need to develop adequate specifications for military dRDF, the following recommendations are presented here.

4.1 PRODUCTION of dRDF

1) Sample dRDF production stream and perform laboratory analyses similar to those listed in the existing contract for all subsequent contractors furnished dRDF pending the development of a comprehensive set of dRDF specifications. In order to assess the effects of material handling and provide quantitative data for determining a course of action to reduce the fines content of dRDF shipments reaching Wright-Patterson, it may be necessary to sample Teledyne dRDF from the pellet mill discharge, truck discharge at the warehouse, and the dRDF being loaded into the rail cars or truck trailers (in addition to sampling from the unloaded pellets at Wright-Patterson).

2) Investigate the potential of separating the inorganic fines from the pellet mill feed using additional processing equipment in order to reduce the ash content of the pelletized product.

3) Minimize handling of the pellets in order to avoid destroying their integrity, which results in the production of fine particulate matter.

4) Spread out stored pellets to facilitate drying and prevent decomposition (and subsequent loss of pellet integrity) through aerobic or anaerobic processes.

4.2 PROPERTIES OF dRDF

In addition to the properties presently specified by the Air Force, the following fuel characteristics need to be quantified in order to provide basic data that are important for determining the material handling characteristics of the dRDF and for understanding, controlling, and optimizing dRDF combustion:

1. Pellet Density
   As-received, lb/ft^3

2. dRDF Size Distribution

3. Ultimate Analyses
   H
   C
   N
   O
   S

4. Volatile Matter

5. Ash Analyses and Ash Fusion Temperature
   SiO_2
   Al_2O_3
   NaO
   CaO
   K_2O
   Fe_2O_3
   MgO

6. Pellet Integrity

7. Pellet Biodegradation

Standard analytical procedures for coal (or draft ASTM RDF test methods) can be used to develop the data for items 3, 4, and 5. Methods for determining pellet density and dRDF size distribution (items 1 and 2) need to be examined and written into the form of a specification. There are several procedures for density and size distribution analyses (including those developed by the ASTM, NCRR, and Cal Recovery Systems) that require review, re-writing, and testing in order to make them specific for dRDF and the needs of the Air Force.

Similarly, a method to measure the integrity of dRDF needs to be developed. Again, there are several methods that are available including those developed by the American Society of Agricultural Engineers, National Center for Resource Recovery, and Cal Recovery Systems. However, these methods need to be reviewed, reorganized, written, and tested in light of the specific requirements of the military.

The biodegradation of dRDF needs to be examined, especially from the standpoint of assessing the integrity of the material over a long period of time (e.g. weeks or months). Certainly some decomposition due to microbial activity takes place within the dRDF after processing. It is possible that the process of decomposition contributes to the degradation of the dRDF during transport and storage. Time, temperature, moisture content, and dRDF composition are some of the factors that influence the rapidity and degree of decomposition. However, work has not been carried out to determine whether or not biodegradation is a significant problem with dRDF. In addition, there are no standard procedures or measurement techniques that have been developed specifically to study biodegradation within dRDF. Due to its potential detrimental effect upon the integrity of stored dRDF, the problem of biodegradation needs to be addressed, if only to lead to recommending temperature ranges for storage, storage depths and volumes (due to heat generation from exothermic decomposition), and dRDF moisture contents.

After sufficient test data are available for items 1-7, the values can be interpreted and subsequently incorporated into a comprehensive set of specifications.

4.3 MATERIAL HANDLING OF dRDF

In light of the fact that the generation and dispersion of fines at the unloading point and during conveyance at Wright-Patterson will

probably remain a problem if the manner of dRDF production and material handling remains unchanged, the only viable solutions to the problem are dust control and collection devices. With respect to the material handling system at Wright-Patterson, covered conveyors with pneumatic dust collection systems and/or water spray systems will reduce the nuisance problem of dust dispersion. Control of dust dispersion at the unloading area is more difficult, but a pneumatic collection system could be designed and installed.

The installation of dust control equipment will present certain technical questions regarding retro-fitting an extensive in-place material handling system as well as economic questions. It should be pointed out, however, that even if pellets were produced at Wright-Patterson, production and dispersion of fines would almost certainly occur due to the degree of handling of the dRDF prior to firing in the boiler.

It is the opinion of CRS that specifying pellet density, moisture content, and size distribution would result in dRDF material that would be of high integrity, easy to handle, and relatively free of fines. Pellet densities of 60 to 70 lbs/ft^3 and moisture contents of 17 to 24 percent are technically achievable and would not unduly burden the dRDF supplier with significant processing costs. Both pellet density and moisture content specifications are required in order to assure that dense pellets are not the sole consequence of a poorly constituted pellet with a high moisture content.

4.4 STORAGE OF dRDF

There are a limited amount of data on the storage characteristics and the behavior of dRDF under static and dynamic loads. Tests to determine the basic bulk flow properties of wood pellets have been conducted for the U.S. Army and reported by Hathaway, et al[a]. In addition, limited tests to ascertain the degree of biodegradation of dRDF during storage have been carried out by the U.S. Navy[b].

The U.S. Army report authored by Hathaway, et al, reports that pressures in a typical conical storage vessel can range from 200 to 600 lb/ft^2, although the report does not cite the depth of the stored material. The tests conducted for the Army showed that wood pellets began to chip and break under a load of about 350 lb/ft^2.

For the case of dRDF with a bulk density of approximately 30 lb/ft^3, the average static load at the bottom of a thirty foot storage silo can be estimated to be in the range of 750 to 1150 lb/ft^2 if wall effects are neglected. Wall effects would lower the range of pressures. The above range of pressures (750 to 1150 lb/ft^2) would be an average over the entire cross-section of the material being stored. Loads on individual pellets could be much higher.

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a) Hathaway, S.A., et al, Densified Biomass as an Alternative Army Heating and Power Plant Fuel, CERL Technical Report E-158, March 1980, pp. 83.

b) Lingua, M., Stability Tests for d-RDF, Draft Technical Memorandum, CEL Naval Construction Battalion Center, January 1981, pp. 27.

In order to address the problems usually encountered when storing dRDF, a test plan should be developed to correlate the integrity of dRDF to the behavior of pellets under loads typical of those encountered in storage silos. A first step would be to collect basic flow and material properties similar to those obtained by the Army for wood pellets. A correlation of these data would be undertaken followed by either pilot studies or full scale tests (e.g. using the Wright-Patterson storage silos). The influence of biodegradation on the integrity of dRDF should be taken into account in the testing program.

4.5 COAL AND dRDF ASH ANALYSES

Due to the propensity of the ash of dRDF and dRDF/coal mixtures to fuse at significantly lower temperatures than the ash of coal, a laboratory investigation is recommended to document the ash characteristics of various mixtures of coal and dRDF. In particular, ash fusion temperatures and composition need to be identified and correlated with the slagging and clinkering that has occurred at all facilities burning RDF or coal/RDF mixtures.

4.6 ANALYSES OF dRDF PROPERTIES

The dRDF analyses presently being conducted by the laboratory under contract to the Air Force, need to be evaluated for accuracy and precision by conducting round robin testing among several laboratories. The reason stems from the fact that analytical procedures for dRDF are in a dynamic state and often are laboratory specific. CRS has found several inconsistencies among laboratory analyses of processed refuse fractions.

In addition, laboratory analyses should be conducted using the latest proposed ASTM procedures. For heating value analyses, the proposed ASTM procedure for RDF-3 should be used.

4.7 dRDF SPECIFICATIONS

Until more data are available, consideration should be given to utilizing as specifications the average properties for RDF and dRDF that are reported in Table 2.2. When additional data and information becomes available, additional specifications can be defined, for example those listed in section 4.2, based upon production technology and user requirements.

Incentive and penalty clauses for exceeding or failing to meet specifications, respectively, need to be addressed based upon the military's requirements and the range in properties that can be tolerated by military boiler units. The development of the property ranges most likely would require discussions with those military personnel most closely associated with boiler firing and fuel procurement.

Wright-Patterson dRDF Analyses Performed by
Howard Laboratories, Inc.

3/31/80 Through 8/27/80

Date Sample Received by Laboratory	High Heating Value Btu/lb Dry Basis	% Ash Oven-dry Basis	MC Oven-dry Basis	Bulk Density lb/ft^3 As-received	-3/8" Fines % As-received Weight Basis
3/31/80	7889	11.16	14.26		
4/07/80	9525	11.02	14.17		
7/01/80	7869	8.35	9.26	35.00	8.65
7/07/80	9787	12.03	9.17	35.00	27.15
7/09/80	9343	10.18	8.38	37.00	4.25
7/14/80	8237	13.59	14.28	28.90	12.55
7/16/80	8390	14.50	19.20	26.70	2.81
7/18/80	9118	21.52	18.70	27.00	7.51
7/21/80	7845	17.88	23.26	23.50	4.43
7/22/80	9345	18.27	22.18	12.22	15.16
7/23/80	7922	15.88	8.92	19.84	13.95
7/24/80	8177	21.28	18.71	21.20	16.51
7/25/80	8833	23.01	31.87	21.82	10.10
7/30/80	7422	18.70	24.90	21.29	15.04
8/18/80	7571	17.12	13.24	33.52	8.06
8/19/80	6436	22.26	19.68	31.40	8.78
8/27/80	5751	20.80	22.03	39.00	22.94
Avg. Std.	8204	16.30	17.2	28.0	11.9
Deviation	1081	4.7	6.6	6.9	6.8

ADDITIONAL REFERENCES

1. Hall, E.H, et al, "Comparison of Fossil and Wood Fuels," EPA Report No. EPA-600/2-76-056, March 1976.

2. Babcock and Wilcox, Steam/Its Generation and Use, 1972.

3. Jones, J.L., and S.F. Radding, Thermal Conversion of Solid Wastes and Biomass, ACS Symposium Series 130, American Chemical Society, Washington, D.C., 1980.

4. Horsfield, B.C, et al, "Agricultural Residues as an Alternative Source of Energy for the Pacific Gas and Electric Company," Department of Agricultural Engineering, University of California, Wain, July 1977, pp 279.

5. Agricultural Engineers Yearbook - 1930.

6. Proceedings of the Sixth Mineral Waste Utilization Symposium, May 1973.